

Antenna on my yacht



FIGURE 1: Radio Wild Bird, (G3LNP/MM or /P) ashore at Arrecife, Canary Islands.

We can avoid the increasing interference to HF reception from domestic electrical equipment, PV systems or internet radiation and overcome antenna planning objections by operating a portable station in the countryside or offshore from a boat. Here are some of my notes and experiences of operating SSB on the lower HF bands from my 11.6m Vancouver 38P cutter Wild Bird of Dartmoor (Figure 1).

I use an ICOM IC-706Mk2G radio with an AT140 automatic tuner. This combination was popular with yachtspersons because removing a diode (see Figure 2) from this radio gave universal frequency coverage to include marine communication channels when using their boat's callsign. This was also desirable for allowing operation on the 5MHz band. Interference to reception is usually negligible after switching off the boat's numerous non EMC-compliant items of electronic equipment, except from HF 'static'. While sailing off West Africa some land-based UK operators, who were Q5 with me, could not receive my signal because of their local noise levels.

HF antennas on yachts

While HF 'weather fax' continues to be received on board, most yachts no longer carry HF radio transmitters. Yachtspersons planning to go far nowadays rely on satellites for communication, meteorological reports and navigation. HF whip antennas were typical for transmission from motorboats but on sailing boats HF antennas were usually formed by adding insulators to a stay that was helping to support a mast. My boat, for example, has a pair of back stays connecting

the head of the single mast to each rear corner at deck level, as shown in Figure 3. Ideally, glazed porcelain rod insulators would be specified because of their minimal capacitance and long slippery insulation path, desirable to minimise the effect of salt encrustation. Apart from their RF insulation function, a stay insulator must prevent the stay from parting if the insulation material fails under excessive mechanical loading. Fail-safe insulators typically rely on a pair of coupled but separated metal loops moulded within a solid rod of insulation material, with a wire-rope cone clutch at each end. Typically, those for yachts having a leakage path of about 15cm introduce 15pF of capacitance [1]. Such an insulator has reactance of $2,800\Omega$ at 3.7MHz whilst the calculated parallel-aspect resistance (R_p) at the feed point of the original single backstay antenna at this frequency was $12,000\Omega$ [2]. Obviously, the insulator becomes progressively less effective with increasing frequency. This was not so much of an issue when operations took place on the now rarely used 1.7MHz to 4MHz 'trawler band', where the 2,182kHz distress channel is still a priority. For higher frequencies, egg-type insulators are more appropriate because of their much lower capacitance whilst still being fail-safe but they have a short leakage path that may make frequent cleaning necessary.

Earthing

The most frequently asked question from radio contacts is: "What is your earth connection?". Some believed that there must be numerous wires extending from the boat into the sea. The primary earth (saltwater) connection is typical and effective at both RF and DC, provided by a pair of copper plates, each about 20cm x 10cm fixed to the hull below the waterline. These have a foam texture to enhance the area in contact with the water. The encapsulated lead keel, that has its glass-fibre case as a dielectric, adds to

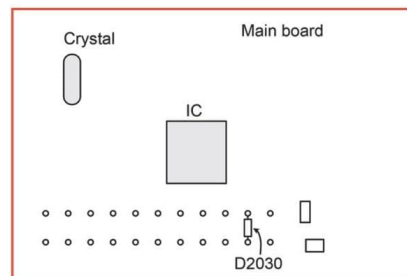


FIGURE 2: The location of D2030, second from the right in the row of diodes on the main board of the radio. It may be removed to permit universal HF transmission.

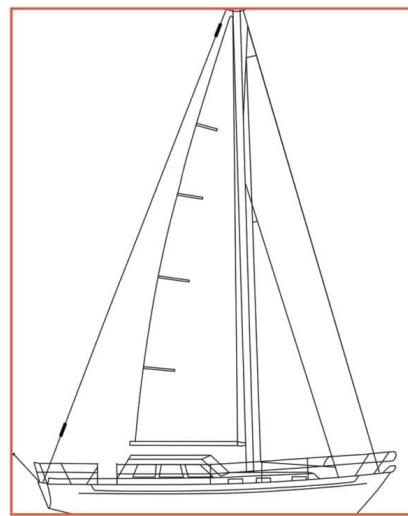


FIGURE 3: The sail plan of Wild Bird showing the insulators in her back stays.

this at RF. Heat transfer plates, also of foam copper, each for the fridge and the freezer, provide more water contact area. The mast and side stays, also known as shrouds, are connected to a similar earth plate, primarily as a protective measure against lightning. Galvanic corrosion of the earth and cooling plates is prevented by sacrificial zinc anodes that add to the water contact area. The propeller also makes a further contribution. To protect onboard equipment from RF current on the braid of the radio-to-tuner coaxial cable, a low-impedance connection to earth for the tuner is made with a short length of 5cm-wide copper tape. Connection between the dedicated earth plates and the other wet items is incidental via the braid of the coaxial cable that is connected to the negative terminal of the 440Ah absorbent glass mat (AGM) sealed lead-acid battery via the radio. Depending on circumstances, the battery charge is maintained by a wind

turbine, a water turbine, solar panels, a diesel generator or an engine-driven alternator.

Personal safety

Radio transmission from vessels has been going on for almost two centuries but I have not heard of a crew member suffering from electromagnetic field radiation (EMF) on a yacht or ship where it is often impractical to keep far away from an antenna. Perhaps only the risk of touching a live antenna, rather than exposure to EMF, was considered relevant in the day when HF transmission from vessels was common. I suspect that, if the EMF limits imposed on land-based stations for personal protection were applied onboard small vessels, they would make amateur/MM and commercial inshore fishing untenable for all but QRP operation.

Only one of my back stays originally had insulators to form an antenna. These were fitted by a previous owner who completed a circumnavigation of the world, one near the top and the other 3m above the cockpit floor. This is a traditional safe configuration, intended to put the 'hot' part of the antenna out of reach, but ignores the insulated wire that completes the length of the antenna by connecting the stay above the lower insulator to an automatic tuner that is, as on *Wild Bird*, typically found below deck. When considering the near electric field it is, therefore, no less than if the insulator was at deck level! The section of the stay below the insulator on *Wild Bird* was not earthed so may not have been safe to touch.

The EMF in the cockpit region is primarily dependent on the electric field around the feed point and that depends on the square root of the product of the power from the tuner and R_p . R_p increases rapidly as the working frequency departs from the resonant frequency so it would be safer if the antenna were an end-fed half-wave (EFHW) type where R_p is typically $4,000\Omega$. Safer still would be an end-fed quarter-wave antenna. R_p would then be the same as the antenna's series resistance R_s of about 30Ω . The magnetic field would then be the predominant source of EMF but unlikely to be strong enough to be a potential hazard to health as it might be from a magnetic-loop antenna. My antenna resonates as a quarter wave near 4.3MHz where we could presumably apply the RSGB's EMF calculator to find a safe distance, but this is likely to be off the boat. When sailing single-handed with EMC-free wind-vane automatic steering or at anchor, I am not concerned by EMF at my radio operating position which is low down in the boat and only about one metre from the earthed base of the mast where the electric field is minimal.

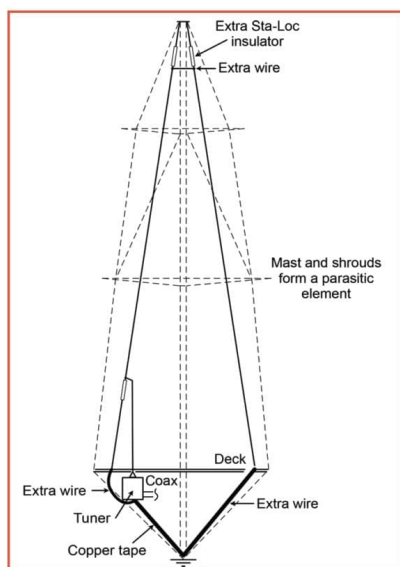


FIGURE 4: The folded monopole antenna element using both back stays. This arrangement provides greater bandwidth whilst allowing more power without potentially increasing the EMF.

Mutual coupling

Because of their closeness, particularly at the mast head, there was considerable mutual electrical coupling between the driven stay, the metal mast and other metallic parts of the standing rigging. The undriven back stay was connected to the head of the mast with the shrouds so whatever they picked up was combined with current induced into the second back stay from the driven stay. The mast, second back stay, boom and shrouds consequently contribute to the radiation pattern in a way that is difficult to predict. Intermediate side and fore stays provide capacitive loading of the mast. The inner and outer fore stays have rotating sail-furling mechanisms at both ends that, with their distance from the earth connection, are impractical to earth. They are, therefore, likely to support significant voltages at deck level. However, this is not a region where any crew or I will likely be active whilst transmitting.

Modelling

Measuring radiation performance and assessing absolute EMF safe distance was not workable; therefore, EZNEC was used to model and verify the expected behaviour of the 17.5m sloping wire antenna over sea water. An attempt to model the currents in the original mast and rigging initially revealed the radiation pattern to be directional with the ratio between maximum and minimum more than 20dB. This had been plain when QSB was caused by the boat swinging at anchor. At 1.85MHz, R_p at the feed point neglecting losses was

theoretically $300,000\Omega$, implying a high electric field strength. The series resistance was correspondingly very low, implying a high magnetic field strength. This was a worst-case combination for EMF! However, the insulator's capacitance would have masked the high R_p value in practice. From a safety standpoint, the fact that the mast and shrouds are earthed implies reduced voltage at and below deck level, making them safe to hold on to. In practice, this was not true for the second back stay which was live at its lower end and easily touched by anyone at the helm. Adding a short thick wire to join it to the earth system proved not to be a clever idea because the model showed even greater coupling between the driven stay and the rest of the standing rigging!

A folded radiator

My solution, prompted by the prospect of adding a linear amplifier and higher-power tuner so that I might be heard better by land-based stations, was to separate the back stays to allow the mast and shrouds to be an equivalent 30cm thick earthed parasitic element. The back stays could then be converted into a folded monopole by adding a top insulator to the second back stay. Folding was completed by joining the back stays below their upper insulators as in **Figure 4**. This shows a simplified view of the rigging of 'Radio Wild Bird' as seen from behind the boat. The advantages of a folded monopole are that R_s becomes typically four times the radiation resistance and the rate of change of reactance with frequency is lower than for a single wire. These factors contribute to a much slower rate of increase of R_p with departure from self-resonance. Consequently, EMF potential is reduced. The rigger was not easily convinced that the lower end of the second back stay would be safe to touch as he did not appreciate that RF voltage was not constant throughout the wires. I, however, was more concerned by the lower end of the driven back stay that was not earthed but connected to the active part via 15pF! Another short thick wire was added to connect this part of the driven back stay to earth.

Performance

EZNEC shows that the folded monopole configuration reduces the computed feed point R_p from $12,000\Omega$ to $1,300\Omega$ at 3.7MHz to 770Ω at 5.3MHz, and to $2,600\Omega$ at 7.1MHz with corresponding anticipated reductions of EMF below that expected from an EFHW antenna. The folded configuration also has the

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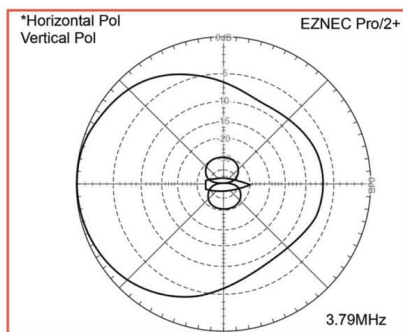


FIGURE 5: The azimuth radiation pattern at 3.79MHz showing 8dBi gain at a 5° take-off angle after converting the back stays into a folded monopole configuration and isolating the mast and shrouds from the radiator to allow them to become a parasitic reflector element.

benefit that (a) the tuned VSWR bandwidth increased because of the lower rate of change of reactance with frequency and (b) higher power was possible without increasing the EMF near the feed point or overstressing the stay insulators, especially at 1.85MHz where R_p , neglecting insulator capacitance, would be 150,000Ω and R_s 3.5Ω. Antenna gain peaks at 8dBi at 3.79MHz, with the radiation pattern shown in **Figure 5**. Front to back ratio is 6.5dB by virtue of the isolated mast and shrouds acting as a parasitic reflector element that is self-resonant near 3.6MHz. This was particularly fortunate if the EZNEC results were correct because 3.79MHz is the activity centre frequency for SSB DX. The direction of maximum radiation is reversed in the CW section of the band where the mast becomes a director. At 3.6MHz, the pattern is like a figure of eight as the back stays and mast have almost equal amplitude currents flowing in them with 180° phase difference. At 5.3MHz, the mast continues to exert some influence as a reflector, yielding a gain of 6.2dBi and a front-to-back ratio of 3dB. At 7.1MHz, the mast is close to an earthed half-wave element that would make it transparent, resulting in an omnidirectional radiation with gain of 6.3dBi. At 1.85MHz, the mast is too short to be effective so the radiation pattern is omnidirectional with gain of 1.5dBi. Compare these results with the highly directional unmodified single back stay pattern in **Figure 6**. To achieve the same 3.7MHz gain performance on land would typically require a four-square phased array of quarter-wave elements, ground of good conductivity and an extensive radial wire earth system but without the benefit of such a low take-off angle. This is because of sea water's high conductivity, as documented by sources like that at [3]. Regardless of the VSWR at the feed point of the back stays, the automatic tuner, designed for matching a single wire, transforms the impedance to 50Ω between 1.6MHz and 30MHz. Above 9MHz

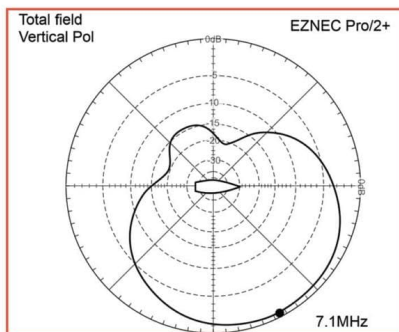


FIGURE 6: The azimuth radiation pattern at 7.1MHz for the original single driven back stay, with the second backstay still connected to the mast.

EZNEC shows the azimuth radiation pattern to be irregularly shaped. This implies QSB problems if the boat's heading changes. Peak gain at an elevation angle of 4° varies between 7.9dBi at 10.1MHz and 4.6dBi at 18.1MHz, with mainly high-angle radiation at higher frequencies.

Adding extra bands

Having modified my 706 radio for general coverage, it was only necessary to set a 5MHz channel in memory for the 60m band to appear in the band selection sequence between 80m and 40m. Similarly, a SW broadcast or marine channel can be added as a band. For example, the 15MHz broadcast band, once in memory, will appear between the 20m and 17m bands. Appropriate front-end and output harmonic filters are introduced automatically but they may not necessarily provide optimum performance outside of the original amateur bands; the tuner helps to offset this tendency.

Operating

The calm conditions for operating on the lower frequency HF bands in European waters unfortunately do not coincide with winter grey line propagation when DX is likely to be worked. The /MM suffix is quite rare, and usually if I work a station who reports me on the DX Cluster, I frequently get lots of calls. As an example, whilst off the coast of Western Sahara, I started a QSO with a friend in the UK on the 80m band but was soon called by the West Coast USA, New Zealand, and Hawaii. The noise level when the land is over the horizon is typically S1 or S2 on the lower bands, and with no S units indicated above 14MHz unless there is a thunderstorm nearby. I never fail to hear anyone who calls me, but on many occasions my signal is below the caller's local noise level. During Covid lockdown, I sailed home single-handed from Lanzarote via the Azores and Madeira but was

not allowed to make landfall to establish an internet or mobile phone connection. Thanks to amateur friends in Scotland and France, my family were kept aware of my progress. Last year, I cruised around Ireland and Wales, and had schedules with friends in Eastbourne on 40m and 80m but we were soon joined by many other UK stations, presumably after being spotted. I have not noticed QSB caused by antenna directivity since introducing the folded radiator. Although I have no EMF measurements, I remain unaware of any symptoms attributed to EMF exposure and take comfort in the fact that my EZNEC results show a large margin between my arrangements and what would be expected from the popular EFHW antenna.

Noisy bottle screws

Some head scratching became necessary when I discovered that noise did not disappear as expected when I first left the coast with the folded antenna replacing the single wire. The whole RF spectrum up to 14MHz was filled with mush in which distorted voices could be heard. There was apparently some nonlinearity that was causing intermodulation between multiple signals received by the antenna. This turned out to be caused by the stainless steel rigging screws! Once they were shorted with thick wire, the problem disappeared. However, the tuner could not now cope on the 1.8MHz band so the rigging screws must have been contributing significant impedance as well as being non-linear.

Noisy PV system

The PV charging system had always been anticipated to be a source of noise. It consisted of two 110W panels with non-slip surfaces that were glued to the coach roof. They drove a pulse-width modulated charge controller that radiated steep pulses, the harmonics of which overrode all but the strongest received signals. The solution was to add contacts of a relay to interrupt the output of the panels automatically when receiving. To achieve this, the PTT facility intended to control a linear amplifier was arranged to switch off the PV system via the relay while receiving.

References

- [1] stalok.com/product-category/marine/insulators/
- [2] When the feed impedance consists of resistance R_s in series with reactance X_s , the parallel-aspect resistance R_p is given by $R_p = R_s (1 + [X_s/R_s]^2)$. For example, a short vertical radiator of impedance $(20, -j100)$ has a parallel equivalent resistance of $20 \times (1 + [100/20]^2) = 520\Omega$. For X_s to R_s ratios greater than 10, the formula simplifies to $R_p = X_s^2/R_s$, with better than 1 % accuracy.
- [3] apps.dtic.mil/sti/tr/pdf/ADA151382.pdf